Airphoto Mapping of Montgomery County Soils for Engineering Purposes

J. D. Mollard
Graduate Assistant, Joint Highway Research Project
Purdue University

Here are described the techniques and methods developed for making a soil map of Montgomery County, Indiana, to be used for engineering purposes. This work is an integral part of a current program to map the soils and drainage of the entire state from aerial photographs. These two mapping programs, which are being carried on concurrently, are a cooperative effort between Purdue University and the State Highway Commission of Indiana.

The application of airphoto interpretation to engineering work is based on the premise that construction and design problems are related to the position and physical properties of surface or near-surface materials. Since the physical properties of the near-surface materials, or soil profile, are revealed by certain elements contained in the airphoto soil pattern, the distribution of these soils can be determined on an areal basis.

The modern trend toward regional design of highways based on soils has provided a stimulus for this type of soil mapping. Another important application of the soil map is locating large granular deposits—many of which, as yet, have not been recognized. Numerous lesser granular deposits also may be outlined on the airphoto; and since these are frequently near the construction site, when located and developed, they provide a source of granular materials for base courses, fill construction, county road surfacing, and sand and gravel for aggregate construction work.

Still another purpose of the investigation was to determine the efficacy of the airphoto for producing detailed soil maps in areas of relatively complex glacial soils. The so-called "complex airphoto soil patterns" are usually associated with complicated soil conditions, such as shallow Wisconsin till or gravel overlying dense, indurated, pre-Wisconsin till. In some instances the Wisconsin drift is shallow on bedrock. Because these patterns contain certain elements which permit their interpretation, several new airphoto soil patterns have been found, thus serving to expedite the progress of the present soil-mapping program.

Maps such as the one discussed in this paper are an excellent source of information for engineers who are planning county and state road programs. A detailed drainage map from airphotos has also been prepared. This drainage map in association with the soil map of Montgomery County will, to a certain extent, be useful to the civil engineer in dealing with his problems of surveying, geology, pedology, hydrology, municipal, highway, and airport engineering.

Engineers have long realized the value of detailed mapping of soil areas and drainage ways; however, they have been faced with the problem of producing these maps at a reasonable cost. To this end the airphoto has proved an accurate and economical expedient, for it constitutes a means by which it is possible to interpret soil patterns and drainage features. Montgomery County, Indiana, has been chosen as a unit to illustrate the use of airphotos for mapping soils and drainage for engineering purposes.

Before airphoto investigations were begun, a survey of the geological and pedological literature pertinent to this county was prepared. Because the work of previous investigators was not directly related to soils for engineering purposes, the literature required translation into engineering terms.

The procedure used in constructing the drainage map requires the preparation of a base map, the marking and transfer of drainage features, and the assembly of the final map. Although this map is designed to cover the field of highway engineering, it may be extended to embrace other types of engineering work. The mechanics used in the construction of the soil map are essentially the same as those used in the drainage-map construction.

In order to give readers who are not familiar with geological terms and airphoto interpretation techniques an opportunity to "get their feet on the ground," as it were, a section has been included which reviews the principles of airphoto identification of soil areas. Since considerable interest has recently been focused upon soil patterns complicated by certain glacial features, a few illustrations have been added which show these patterns.

This paper contains many airphoto and ground illustrations. Several of these have been so placed—by matching pairs of adjacent prints—as to enable the reader to obtain from them an optical reception of the third, or vertical, dimension. The "relief" may be obtained with the aid of stereoscopes, merely by centering the eyepieces over the line of contact of the prints. Often, however, some practice is needed before this relief is evident. The simple stereoscopic devices used for interpretation are available commercially from nearly all manufacturers of optical instruments.

A large amount of field investigation, which was necessarily confined to observations within highway rights-of-way and along stream channels, was employed for checking this work.

Construction of a Drainage Map

Prior to the construction of the Montgomery County soils map, a drainage map was prepared. The construction of the drainage map is introduced here since drainage characteristics offer a clue to soil types as well as topography. Moreover, the mechanics of construction for the soil map are very similar to those described for making the drainage map.

A tracing from the General Highway and Transportation Map of Montgomery County (3 inches equals 1 mile) was used as a base map. On this map the final drainage was drawn.

Before drainage marking was begun, an uncontrolled mosaic was formed by matching together alternate vertical photographs. On these photos, all section corners were located and marked with a wax crayon. The photographs were then marked for drainage. This involved marking all visible drainage features, including both natural and man-made.

A classroom reflectoscope, mounted on a sliding shelf, was used to reduce the scale from three inches to one inch per mile. The drainage features from the airphoto were transmitted through a system of lenses onto a working drawing. These working drawings (one township each) were then assembled, and from them the drainage was traced to the final base map. The drainage features were carefully checked and inked.

Figure 1 shows the drainage map prepared from aerial photographs. On this map, double lines indicate major streams; heavy single lines, small streams or creeks; and narrow single lines, intermittent streams.

Uses of the Drainage Map

The potential value of the drainage map (see Figure 1) lies in its accuracy and detail, which enable the interpreter to obtain from it an over-all picture of any area. The drainage pattern will aid in the interpretation of soils and frequently in the determination of the character

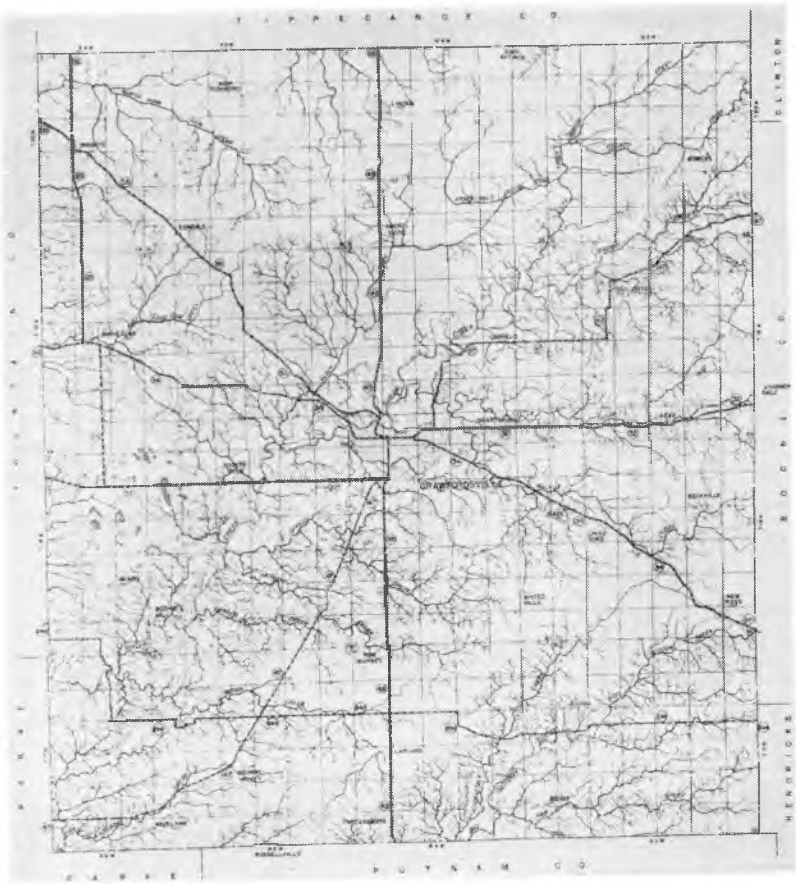


FIGURE 1

Drainage map of Montgomery County.

of the underlying rocks. For this reason it is desirable to study the soils and drainage maps more or less hand-in-hand.

Elements of the drainage map which give clues to the type of soil and rock are several: (1) the general directional trend of streams; (2) abrupt changes in their slope and courses; (3) variation in their width—often caused by bedrock; (4) disappearance of stream channels upon entering a gravel terrace with shallow overburden; (5) meandering nature of stream courses; (6) shape and width of gullies and small stream valleys; and (7) changes in gully shapes upon erosion to a very dense, subjacent till.

For the most part, the drainage map will give an indication of the relief—that is, the roughness or flatness—which can be expected within

FIGURE 2

These two vertical photographs illustrate the difference between drainage patterns in dissected (above) and level terrain.

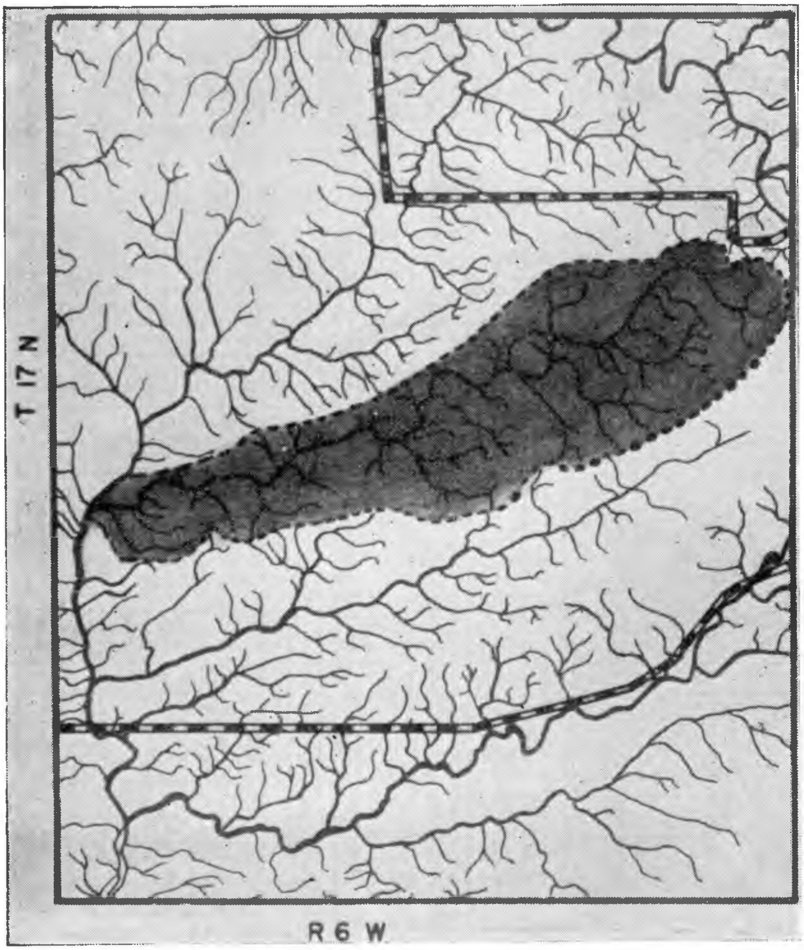


FIGURE 3

Use of the drainage map for computing watershed areas in rough terrain.

any area. In areas where the tributaries are stubby and angular, the soil mantle is frequently underlain by a rocky structure. In contrast, long, straight streams are often a feature of level to gently undulating topography. Examples of these are illustrated by Figure 2.

The map can serve as an economical expedient in highway and airport reconnaissance for location, water development projects, and flood control. In highway planning, the number, location, and approximate size of drainage structures can be calculated, and a tentative cost estimate made.

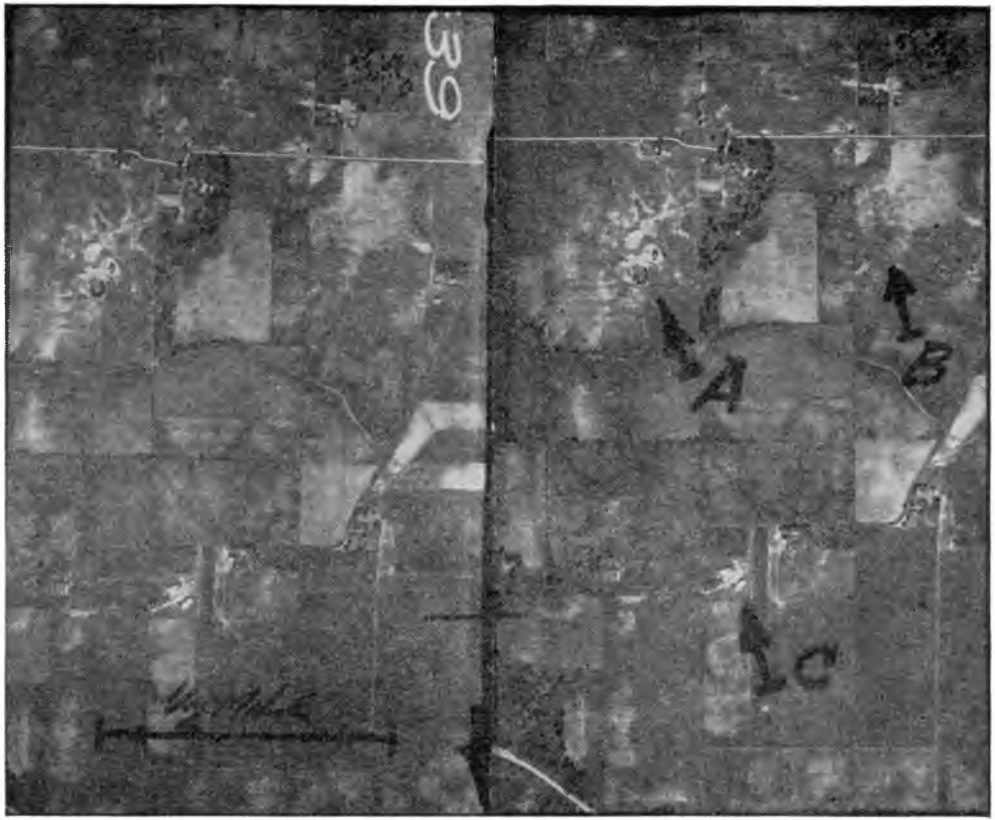


Figure 4

This stereopair contains an example of three kames found on relatively level terrain. Both "A" and "C" have been opened up and are now being worked. Steep sides and isolated positions aid in identifying these deposits as kames.

Another application of the map concerns information regarding watershed areas and conditions affecting runoff. It is an easy matter to outline the watershed areas and measure their areas with a planimeter (see Figure 3). In this way, the size of any watershed can be determined. Such information, when used in runoff formulas, assists in making an economical and adequate design of culverts and other drainage structures. The accuracy of this method will, of course, depend on the type of topography: watershed areas in flat land will obviously

FIGURE 5
This ground photo illustrates the relief exhibited by kames.

be subject to greater inaccuracies than comparable areas in rough, or dissected, terrain.

Principles of Airphoto Indentification of Engineering Soil Areas. The technique of identification of engineering soil areas from aerial photographs is acquired by careful study of the elements which compose what has been termed "the soil pattern."

It is pertinent to mention briefly what is meant by soil patterns. To the untrained observer, an examination of the aerial photograph reveals little except, perhaps, a variation in color tone; yet to the trained

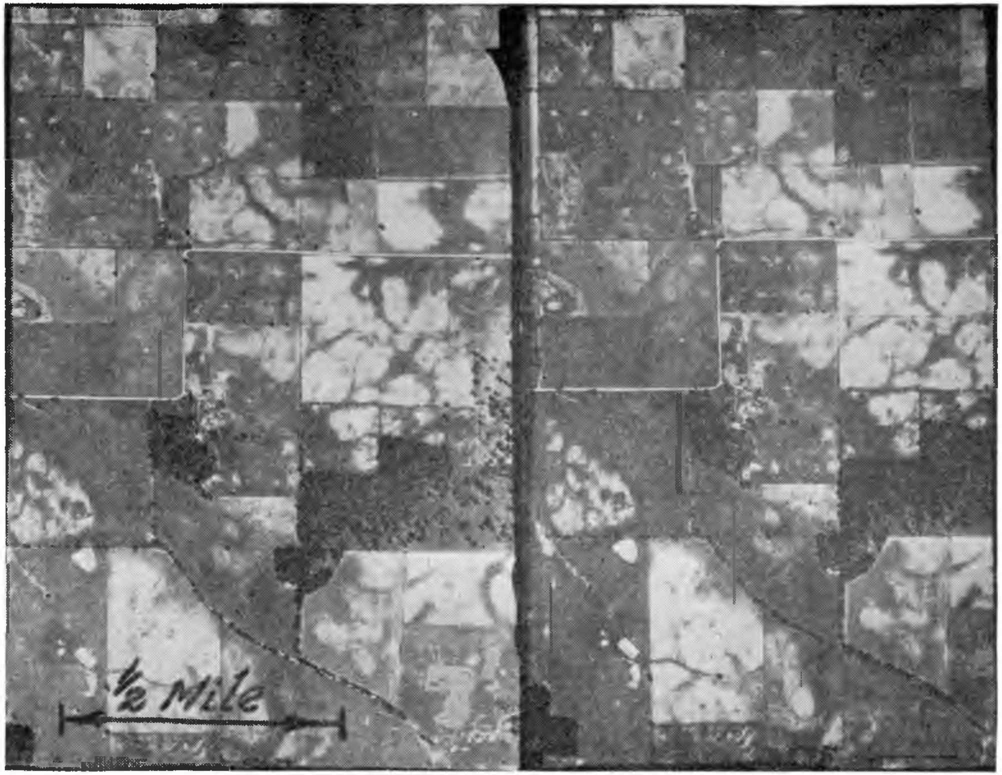


Figure 6

An esker deposited in a glacial or subglacial channel. Though scarcely a half mile in length and 100 yards in width, it rises abruptly to heights ranging from 15 to 40 feet (*11*, p. 108). It is curved, with its concavity toward the northwest. This deposit is known as "Hazelrigg esker and trough." The main airphoto elements are a well-defined crest, shape, and topographic relation.

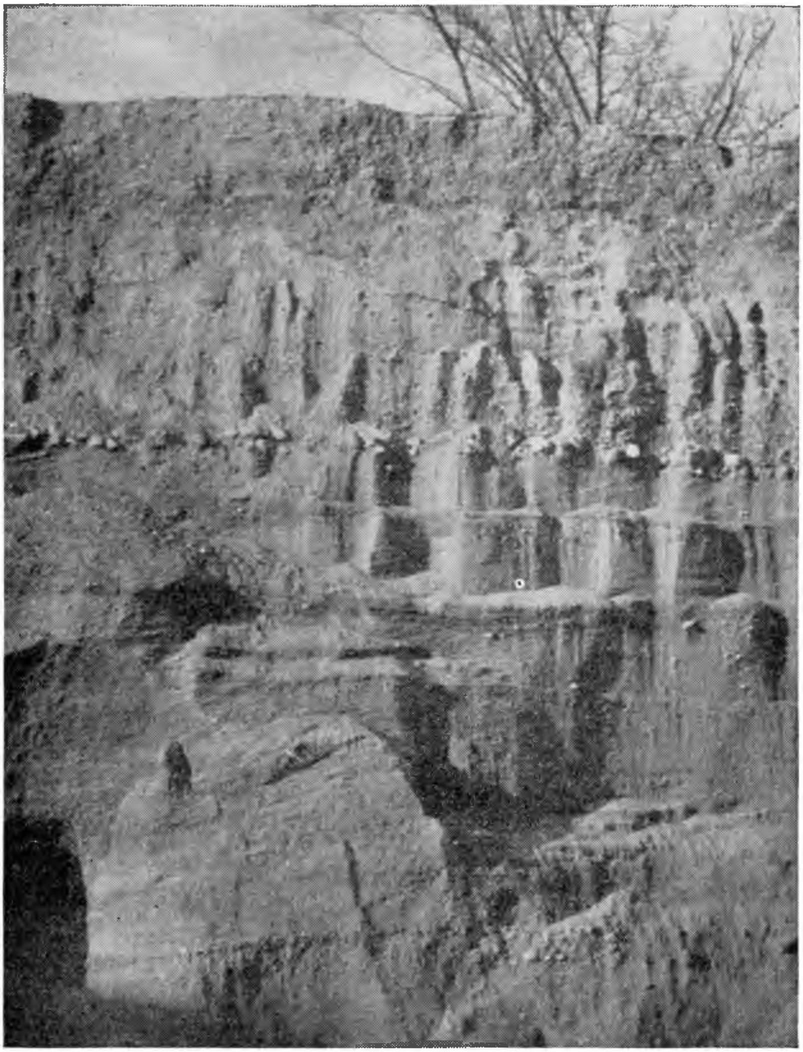


FIGURE 7

Stratification and cross-bedding formed by the sorting action of water. This terrace is underlain by pre-Wisconsin drift.

observer a soil pattern is readily discernible. This pattern, as seen in aerial photographs, is the result of natural and human forces acting on the original material from which the soil was derived. The elements that make up the soil pattern are visible features which are largely a result of physical properties of the soil profile. Among the elements that form soil patterns are land form, soil color, erosion features, surface

FIGURE 8

This ground view was taken along a large gully in the gravel terrace west of Crawfordsville. Note the uniform contact line between pre-Wisconsin drift and overlying gravels. At the left of the picture, gravels extend to the bottom of the gully, signifying a filling-up of the dissected old drift topography.

drainage, land use, vegetation, and others such as micro-relief and farm practices.

Some of the elements of the soil pattern may be altered by changes in climatic zones, but the fundamental over-all pattern will remain the same for a given soil profile regardless of geographical location. The reason for these alterations is that climate affects, to a large extent, the type and amount of vegetative cover, as well as soil colors. Fortunately, in instances where some of the elements are unreliable, a proper evaluation of the remaining elements will usually give a clue to the soil type shown on the airphotos.

Gully shapes and systems reveal certain properties of the soil profile; whereas color patterns often reflect ground-water conditions. Each element, however trivial, has some significance in identification of the soil pattern and may, in turn, be related to the engineering properties of the soil.

These patterns change and their ease of interpretation varies with the type and structure of the underlying rock as well as with ground-water conditions. Moreover, the time of year at which the photographs were taken and the photographic processes used have an influence on the contrasts of the individual contact prints.

In general, where these soil patterns are duplicated, similar geological and pedological conditions have prevailed. This is true because physical properties of the soil are related to geological and pedological processes of soil formation. Coupled with these forces of nature is the rôle of man in his agricultural and industrial development of the land. Some common man-made elements on the photos are artificial drainage (both internal and external), erosion-prevention measures, gravel pits, quarries, field shapes, and the like. All these elements must be carefully studied and weighed; some are less reliable than others and, therefore, may be used as corroborative evidence only.

Although experience is an essential for identifying soils from airphotos, photo-analyses should seldom be regarded conclusive without adequate field checking.

Construction of the Soil Map

The soil map was prepared by means of the principles of airphoto interpretation of soil areas. The mechanics of scale reduction are similar to those described in the construction of the drainage map. In order to facilitate field checking, in the event that in the future more refined soil information might be required, the various soil areas were marked with different colored china-marking crayons. A full scale map has been made to illustrate similar soil areas on the airphotos and on the soil map. (See Figure 11.)

Field Checking

As in the case of the drainage map, a large amount of field investigation was employed to determine the effectiveness of this type of soil mapping. It was found that soil boundaries on the map were in keeping with the classification as indicated by the legend. For example, in areas where varying depths of gravel mantled, almost completely, pre-Wisconsin drift, the entire area is shown as, simply, gravel terrace.

Intepretation of Soil Areas—Their Engineering Significance

It is the purpose of the following discussion to list soil areas contained in the legend of the soil map; to mention briefly their geologic origin; to disclose the airphoto pattern elements pertinent to each soil

FIGURE 9

These Pleistocene conglomerates are found in deep gullies along Sugar Creek. They are commonly associated with pre-Wisconsin drift.

area; to describe, generally, their soil profiles; and to discuss their engineering importance. The airphoto pattern elements are stated in the following sequence: land form, color pattern, surface drainage, erosion, and vegetation and land use. If certain of these elements are considered non-essential for correct interpretation of soil patterns, they will be omitted from the text.

WATER-LAID MATERIALS

During the melting of the great ice sheets, water-laid granular materials were deposited in many topographic forms. In Montgomery County these deposits are found as kames and eskers, outwash plains, modified kettle-kame, and stream terraces.

Eskers and Kames. Eskers and kames consist of mounds of sorted sand and gravel covered by a few feet of topsoil. They are deposited in tunnels or subglacial chutes beneath or within the ice. These eskers, or tunnel fillings, produce a network of conspicuous serpentine ridges which occur indiscriminantly across Montgomery County. Kames are hills, or mounds, of stratified sand and gravel that accumulated in pockets within the ice (*13,* p. 105).*

The main airphoto identifying element of eskers and kames is a characteristic shape or land form. Eskers are characterized by steep sides, narrow width, and variable length. The longer, more winding ridges are more easily discerned. Kames may be isolated (see Figure 4), as in the northeastern part of the county, or in groups such as those found southeast of Wingate.

Where kames and eskers have been formed, light tones are apparent along the crest of these ridges. This light color tone is, in some instances, manifested by gravel pits, which appear as white pockets along the crest of these deposits (see Figure 4). Dark color tones surrounding the base of these deposits are commonplace. This is because they are often situated in troughs or old abandoned channels, partly filled with peat and muck. An excellent example of this situation is illustrated by Figure 6.

Surface drainage is limited because of the texture of these land forms, although in places where the topsoil is silty and the sides steep, excessive gullying may occur. In instances where these forms are blanketed by a vegetative cover, however, erosion seldom occurs.

The vegetative cover on these land forms is variable. Where a nest of eskers is situated in a strong moraine, usually the natural forest cover still remains. The steep sides and narrow width of these deposits, in addition to porosity, makes them poor agricultural areas.

That there is very little profile development on these formations is due, in part, to their texture, shape, and relief. The depth of topsoil varies, but, in general, it is thinnest at or near the crown and deepest toward the base. The largest eskers and kames—that is, those most easily recognized from the airphotos—have only two or three feet of overburden at the crown; the relatively low, broad ridges, on the other hand, have a much thicker shell.

Because these granular deposits are both numerous and scattered in this county, their location and areal proportion is of great significance to the engineer. Although their most extensive use is for surfacing county roads, they are often employed for base course and fill construction, and for aggregate in concrete pavements and building construction.

Granular Terraces. This glacial feature was formed by large volumes of glacial meltwater, carrying sediments that were deposited as

*Italicized numbers in parentheses refer to entries in the bibliography at the end of this paper.

terraces along preglacial or glacial channels. Because these sediments are water-deposited, a cross-section in any direction shows numerous laminated beds, intersecting at different angles, and containing all particle sizes from silt or fine sand to coarse gravel. (See Figure 7.) Along the Wabash River, for instance, the terraces are vast and usually markedly uniform in land form, position, and relief; however, in Montgomery County, frequently the terraces are dissected and, instead of being 50 to 100 feet thick, are relatively thin, lying on either a very dense drift (pre-Wisconsin) or shallow rock. Since a stream may have one or more terraces at different elevations or, on the other hand, none, the aerial photographs are extremely valuable, both in expediting the location of these terraces and in estimating their relative depth and areal proportions.

The land form pattern associated with typical gravel terrace or valley trains along major streams is easily recognized by its cross-section and relief. However, where the terrace has been influenced by such factors as shallow rock or old drift, the land form pattern and other elements become increasingly difficult to evaluate. This is true in many instances in Montgomery County.

The land form of the gravel terrace west of Crawfordsville is typical: flat-topped, benchlike, and situated between the recent alluvium and upland. Sharply incised V-shaped gullies form along the densely wooded terrace face. Where gullies have formed along the valley wall and discharged their load upon the terrace, small alluvial fans form and the water disappears into the porous substratum. East of Darlington, on the south side of Sugar Creek, is an old dissected terrace. (See Figure 12.) If at one time this terrace possessed any of its usual geomorphic characteristics, they have been removed by subsequent erosion and stream action. Here the topography is undulating, with small isolated knolls resembling kames. Fortunately, other airphoto elements are sufficient to enable the interpreter to identify this land form. Terrace remnants are formed along the bottoms of the large stream valleys. These insular, relatively flat-topped remnants represent the destructional erosion of gravel-filled valleys. Excellent examples are found on the Sugar Creek flood plains. (See Figure 11.)

The over-all color pattern of the terrace in areas of sparse vegetation is white to light gray. This is perhaps the most striking element of terraces when the soil pattern is first observed. Where the terrace has a thin overburden and lies upon an impervious stratum, a sinkhole-like pattern is produced. Here the general color tone, markedly white, is dotted with small, uniformly round, dark gray to black infiltration basins. In this county the gravel terraces do not have the "current-markings," which are often ascribed to large gravel terraces along the White and Wabash Rivers.

Because these terraces are composed of stratified, coarse, glacial materials—namely, gravels, sands, and some silts—they are well drained internally. There is, therefore, very little external drainage on this

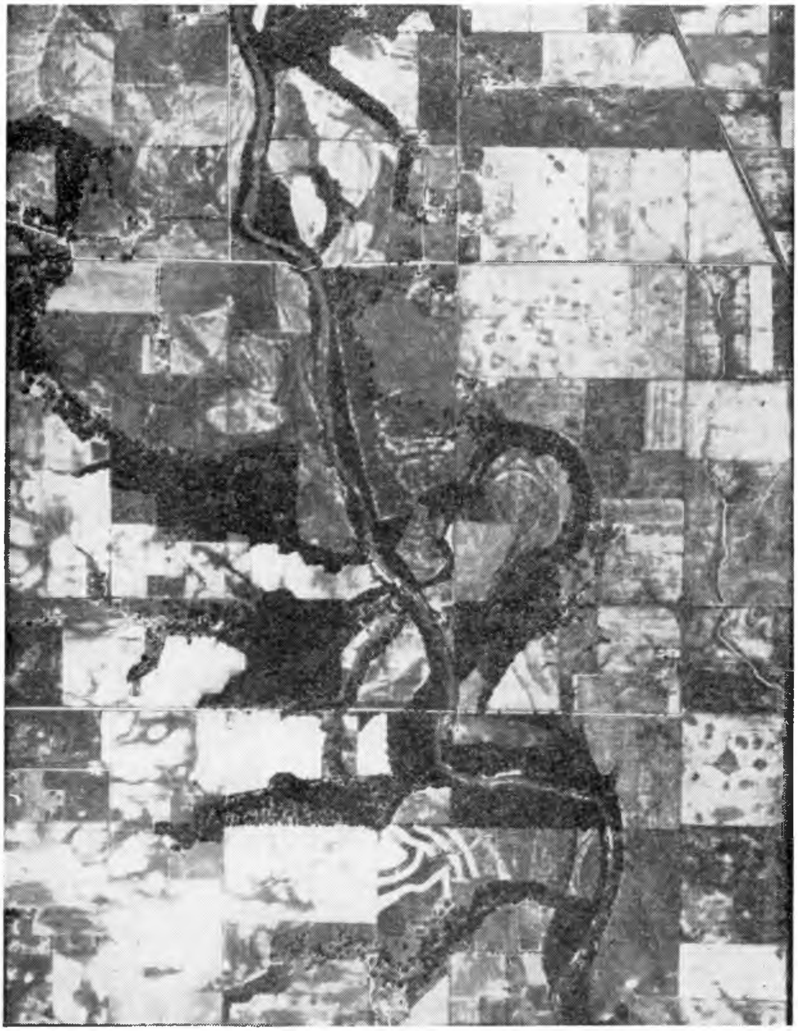


FIGURE 10

This vertical photograph illustrates the airphoto pattern of a gravel terrace underlain by pre-Wisconsin drift. The dark-colored, sinkhole-like depressions (lower right) indicate an impervious substratum.

land form. Where the overburden is deep, occasional channels form and carry water from the upland to the principal streams. (Note the channel in Figure 12.) Small, so-called infiltration basins, through which water percolates, reflect the porosity of the subsoil. They are frequently misleading, for, in several instances, they resemble limestone sinkholes.

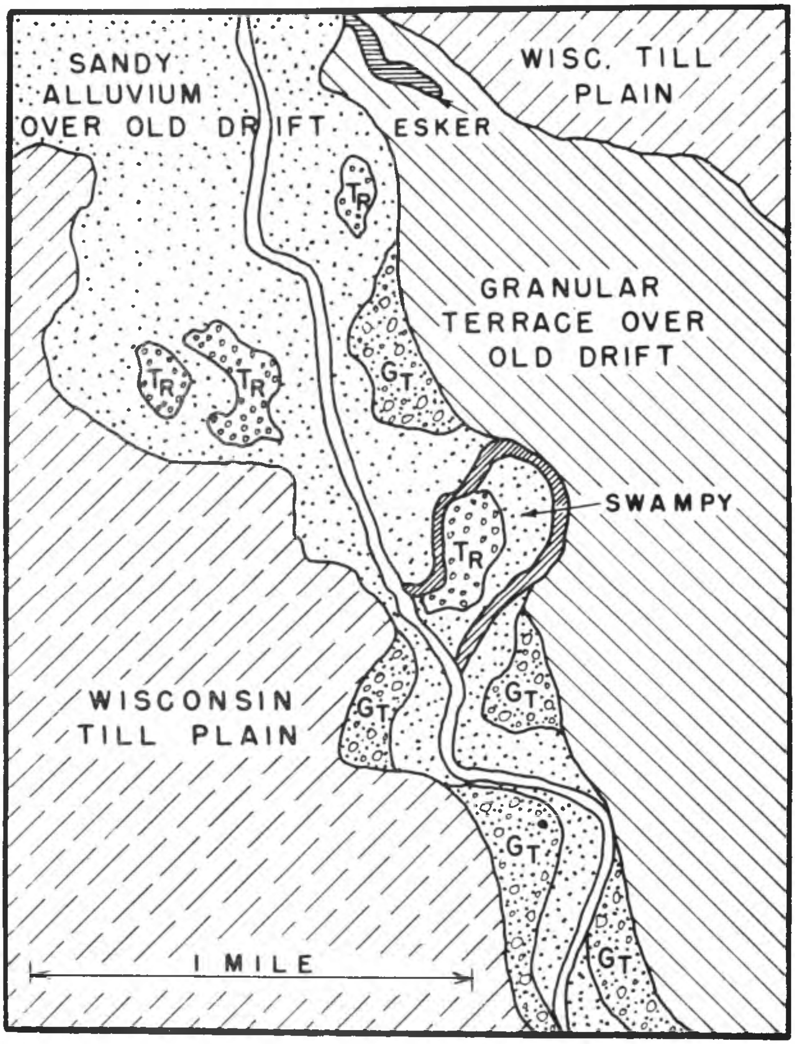


FIGURE 11

This soil map made from the airphoto in Figure 10 shows the amount of detail which can be obtained in some areas. TR represents terrace remnants and GT represents terrace gravel—both are situated on the present flood plain. (Note that the present channel has straightened its course, forming an oxbow lake.)

FIGURE 12

Dissected gravel terrace. The light color tones, topographic relationship, and short gully systems mark this area as a gravel terrace. Several of the common features of this land form are absent, namely, a level topography and good internal drainage.

The profile development on this deposit is shallow; it rarely extends more than seven feet, with an average of four to seven feet. The topsoil consists of silts and silty clays, usually underlain by three or four feet of sandy clay. The gravel below this overburden varies considerably in depth; and in places it occurs only as a thin cover, three or four feet deep on pre-Wisconsin drift.

The engineering importance of gravel terrace soils is much the same as for kames and eskers, inasmuch as they are composed of the same texture. However, because this land form very often occupies a large area, its physical characteristics may well affect design, construction, and performance in these localities. Usually these soils are ideal for subgrade, and it is necessary to provide for only a minimum of drainage. Occasionally, however, if the overburden is deep and plastic, some form of preparation will be required.

Modified Kettle-Kames. Although the origin of this deposit is somewhat indefinite, both the topography and texture can be identified from the airphotos. The topography resembles a dissected outwash plain in which numerous knobs, depressions, and ridges occur. Since this land form lacks the common level skyline characteristic of outwash deposits, the area has been called "modified kettle-kame."

This deposit has a so-called "knob-and-basin" topography. The knobs are frequently aggregated and vary considerably in height above the surrounding basins and elongated sags.

The soil colors accompanying these granular deposits give an important clue to the texture. Although a cursory examination of the color pattern might reveal this area as Brookston-Crosby, upon closer scrutiny marked differences in these airphoto patterns can be detected. There is a sharp contrast between the light and dark color tones on the kettle-kame land form which follows a contour near the base of the knolls. An excellent example of this color contrast is exhibited in Figure 13. In many cases this contour occurs where the water table, being high, intersects the ground line, causing the color pattern to change within a very few feet. The depressions are dark colored, indicating that the kettles are poorly drained and probably filled with ponded organic silts and silty clays.

Very little surface drainage has developed on this deposit because of the porosity of the subsoil. Nevertheless, minute gullies are present which have formed on the sides of the steepest knolls. These gullies appear on the photographs as thin white threads, denoting the sandy texture of the area.

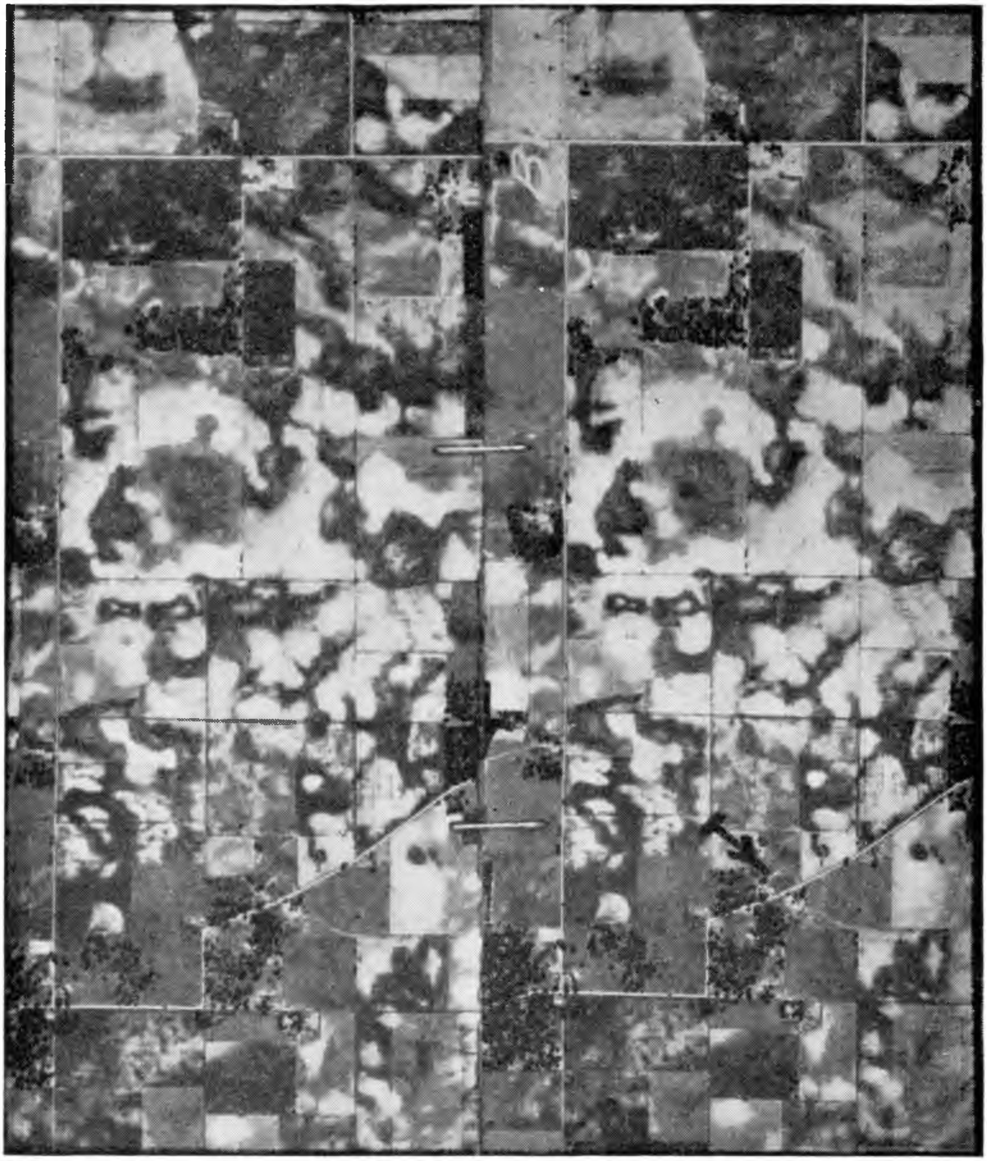


FIGURE 13

Modified kettle-kame. The main identifying elements of this land form are color and relief. There is very little blending of the light and dark tones. The contrast in colors is marked and follows the base of the hills. There is very litt'e connected surface drainage, which is mostly internal because of the coarse texture of the su'bsoil. It is important that this pattern not be mistaken for a Brookston-Crosby till plain (*12,* p. 67), which, in many respects, it resembles. The arrow (lower right) points to a gravel pit.

This land form shows very little overburden. Along the sides and on the crests of the hills a silty topsoil has developed. In the basins the profile development is deeper, as can be seen from Figure 14.

Highway performance on this land form is good because of the coarse-textured subsoil. Pavement in cut sections is directly upon this soil; whereas the fills rest on organic silty clay soils.

Outwash Plains. Outwash deposits consist of sorted sands and gravels. They are deposited in front of a terminal or recessional moraine or other land features in wide areas of relatively low land where the waters are free to spread without being strictly confined. Outwash plains are usually interrupted by pits that contain small ponds or muck-filled depressions. These depressions, sometimes connected, will vary from a few feet to several miles across. Remnants of abandoned channels give a bench effect to the topography.

FIGURE 14

Profile development in the basins of the kettle-kame area. "A" horizon is composed of organic topsoil (black); "B" horizon, which extends to the bottom of the cut section, is a silty clay; "C" horizon, or unaltered parent material, is composed of sand.

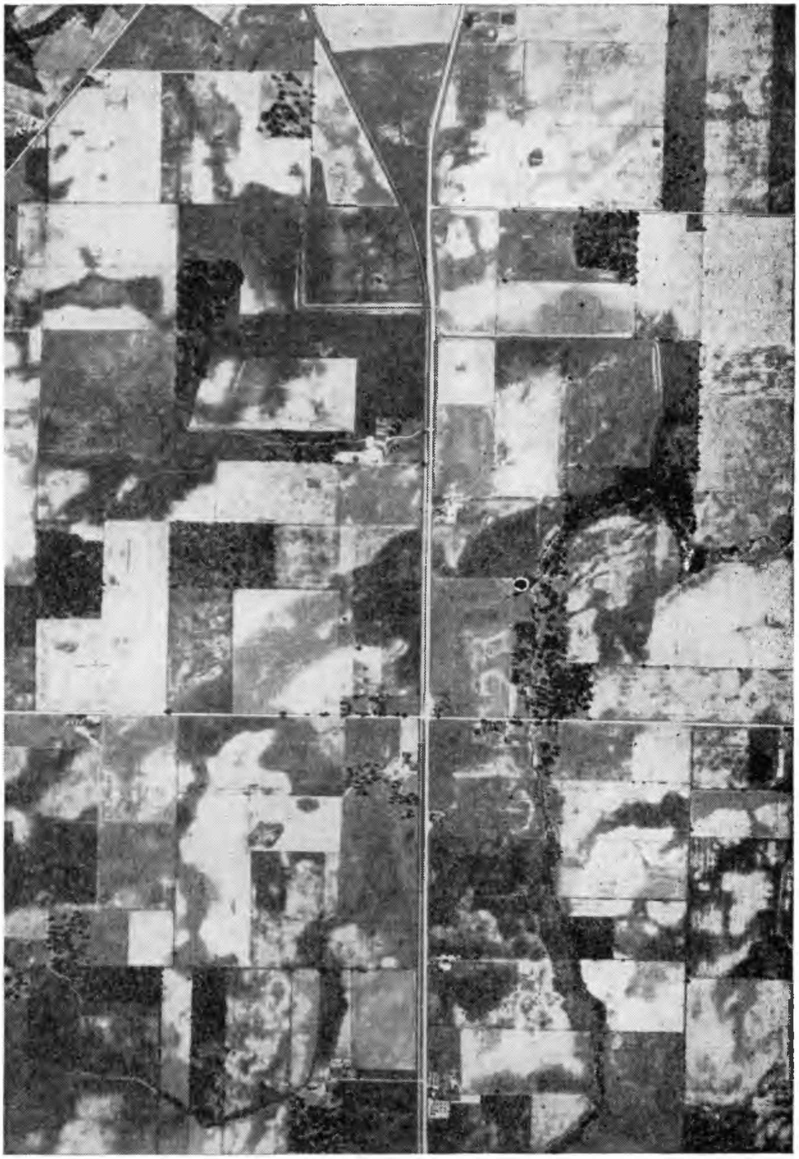


FIGURE 15

Channelled appearance assumed by an outwash plain. The depressions are dark-colored and usually contain open drainage ditches. Both erosion and surface drainage are at a minimum in this area.

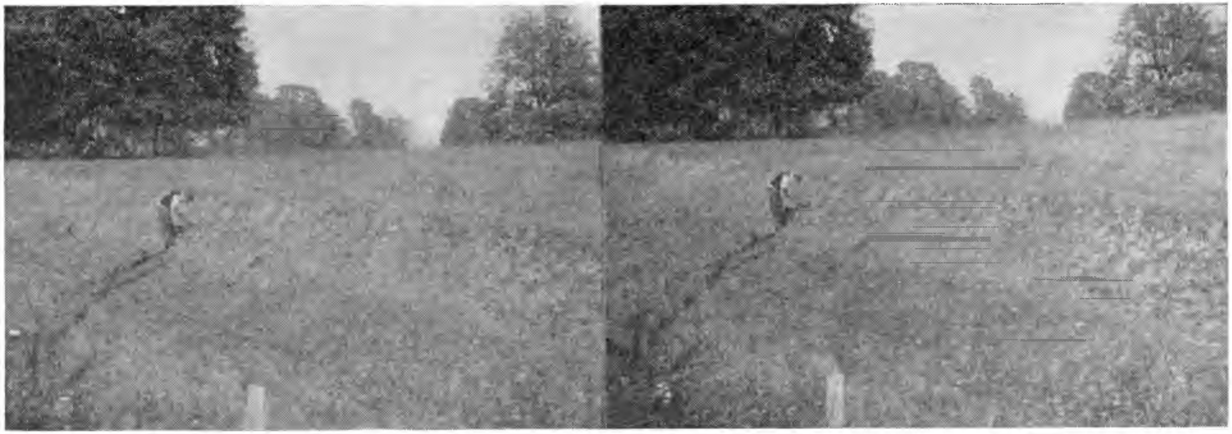


FIGURE 16

A stereopair denoting the change of slope at the line of contact of the silty topsoil and the underlying gravelly sands. It is interesting to note that cattle have made a path along the surface of the more stable granular subsoil.

The land form of the outwash plain in this county is generally level although certain areas assume a slight benched or terraced appearance.

The soil color of outwash plains responds to its concomitants: coarse texture, level relief, and high ground-water conditions. Light colors predominate the general area; black to dark gray outline the pits or depressions and the muck-filled channels. Perhaps the most significant feature of the drainage pattern is the sharp line of demarcation between light and dark tones depicting sharp variations in texture as well as relief.

Drainage is almost entirely internal over outwash areas as a consequence of the permeability of the subsoil. Because high ground-water table commonly accompanies this type of deposit, dredged ditches are frequent. On the whole, surface drainage is lacking, except in areas of flat-lying silts and silty clays. These are revealed in the airphoto as dark, depressed channels.

The granular-textured outwash plain in this county is covered by a friable silt mantle, shown in Figure 16. The depth of silt on this deposit varies and is more shallow toward the center and thickest along the borders. In various localities silt has been carried downward into the upper horizons of the gravelly sand subsoil by percolating waters. Moreover, at intervals along the Sugar Creek bluffs, shales and shaly sandstones occur only a few feet below the surface of the ground.

Highway problems for this area are substantially the same as those mentioned for gravel terraces. The granular subsoil makes this area an excellent source of borrow material. Occasionally the nature of the silt horizon, if thick, does not provide full utilization of the properties of the gravel beneath.

Lakebed Soils. Lakebed or lacustrine deposits are formed where large glacial lakes have become impounded by a moraine or some other land feature. Lakebed sediments consist of clays, silts, and some fine sand, all well sorted, that have settled out by water action.

The land forms of the lacustrine deposits of this county are slightly more undulating than similar areas of these soils in the state, being generally level, broken only by slight swells or rises.

The gentle rises are manifested by light color tones. For the most part the over-all color pattern is dark gray, indicative of depressed topographic position and a rather high ground-water condition.

The surface drainage is at a minimum in these areas owing to the low gradients of the streams. These streams, which have become entrenched, meander in the upper horizons of the profile. The main drainage ways in these deposits are artificial, where farmers have attempted

FIGURE 17

Lye Creek lakebed. This photo shows the contrast in soil color and airphoto pattern between the muck-covered lakebed (dark area) and the Wisconsin till plain (mottled). Note the uniform dark color of the lakebed area, caused by (1) a high ground-water table in flat topography and (2) characteristic swamp vegetation, overlying about three feet of muck (*2*, p. 405).

to lower the ground-water table. Where gullies have developed, they exhibit the typical lakebed form—that is, broad bottoms, "softly" rounded slopes, and low gradients.

Rectangular road and field patterns are an indentifying element of this type of deposit. These two features indicate flat topography. Ditching is a necessity, both for agricultural and engineering purposes.

Because of their fine, uniform texture and position, these soils are poorly drained. During certain seasons of the year, principally spring and fall, the water table is high, maintaining the soil in a plastic state and effectively reducing its supporting power.

Alluvium. The name "alluvium" has been ascribed to all those water-laid deposits occupying the first bottoms of the principal creeks of the county. Much of the area designated as alluvium is subject to periodic floods, at which time fine sands, silts, and clays are deposited. Areas receiving these deposits are called recent alluvium.

FIGURE 18

Sandy alluvium. Coarse-textured alluvial deposits are preponderant along Sugar Creek (above). Note that on the inside bend of this creek (lower right) circular current sweeps occurs (arrow) on the valley floor. Light color tones and absence of surface drainage reveal the porosity of this soil area. A terrace remnant, TR, has been outlined on the alluvial plain.

Two areas of alluvium have been shown on the soil map and are differentiated on a textural basis: one is predominately fine sand and contains gravel streaks and pockets; the other is fine sands, silts, and clays. No estimate can be made as to the size and number of the gravel pockets in the former.

There are two types of airphoto patterns for soils in the creek bottoms, whose interpretation can be stated briefly. The sandy alluvium soil has an ashen-gray color pattern, marked by light streaks indicating current scars. Relief is usually slight; however, where current section was strong, distinct ridges have formed. In areas such as these, surface drainage is completely lacking. The narrow dark bands, which follow the small creeks, can be outlined without much difficulty. These soils have been referred to as "meadowlands."

The coarse-textured alluvial soils provide a well-drained subgrade giving fair to good performance. According to the importance of the

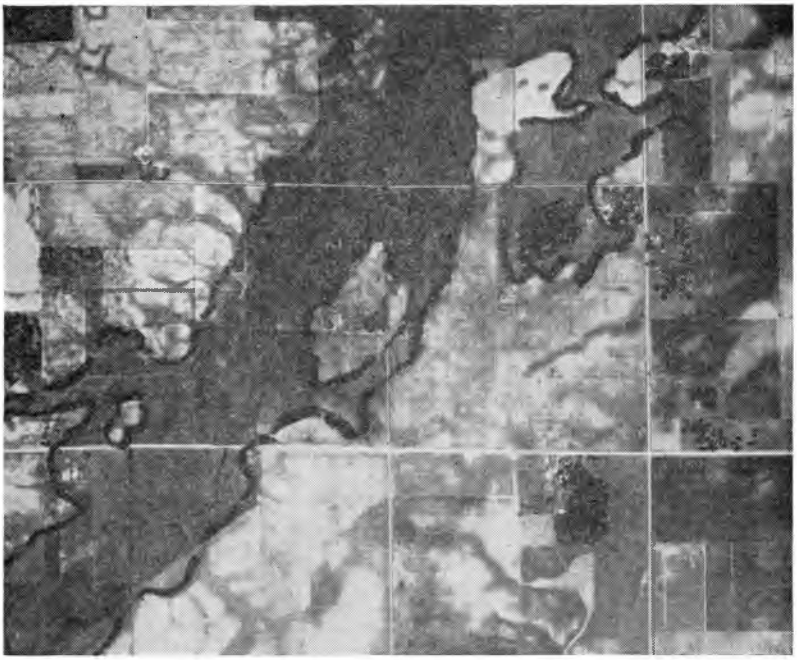


FIGURE 19

Silty clay alluvium. The dark color tone and meandering nature of the small creek in this old channel are indicative of these fine-textured alluvial sediments. As the streams in these channels increase in size and depth, the alluvium becomes predominantly sands, with lesser amounts of silts and clays.

road, provision should be made to place the grade above average flood stage. The fine-grained alluvial soils are undesirable as a subgrade, and in addition they are subject to flooding. Poor drainage conditions maintain these soils in a plastic state under most circumstances.

ICE-LAID DEPOSITS

Moraines. Briefly, moraines are a belt of accumulated drift which formed in front of the glacier when the ice border was stationary for a time. This drift, as a consequence, assumes the form of numerous irregular hills, depressions, and ridges.

In Montgomery County, the land form appears as a belt of accumulated drift—a maze of hummocks, crooked uneven ridges, and numerous depressions, many of which contain small ponds. The topography of these moraines varies considerably from place to place in cross-section as well as in length.

The moraines of this county have no well-defined color pattern. Sharp color contrasts seldom occur between light and dark tones, except in the loess areas. The size of light-gray areas (along the top of hills) is small; ashen-gray areas follow the swales; and dark-gray to black tones represent muck-filled depressions (notice the irregular black areas of Figure 20). The color pattern alone seldom identifies this land form but must be used in conjunction with relief and other identifying criteria.

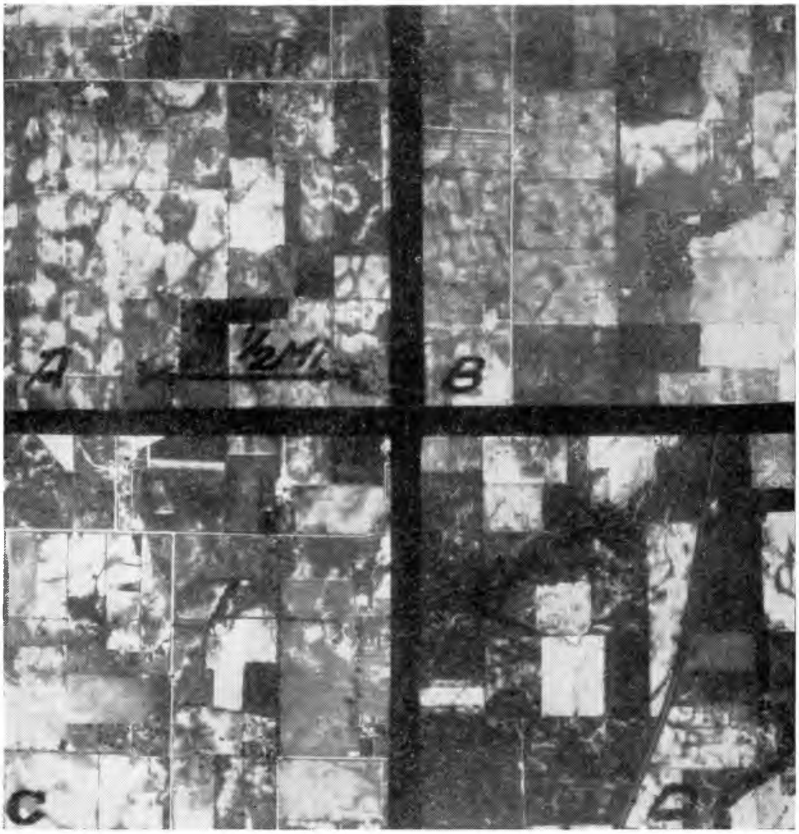


FIGURE 20

These four vertical photographs illustrate the variation in airphoto soil pattern of moraines in this county: (A) granular kame moraine, north of Elmdale; (B) semigranular moraine, northeast of Waynetown; (C and D) till moraines, exhibiting strong relief, north of Alamo and southeast of Crawfordsville respectively.

The surface drainage of moraines is influenced by both relief and texture. Where basins are prevalent the drainage is local and gully systems are short and relatively straight. Small channels flow radially from the crest of the moraines and enter principal streams.

Between Yountsville and Alamo the hills are covered by a few feet of loess. Here the surface drainage is in the form of small, U-shaped gullies. These can be easily seen on the photos. (See Figure 26.)

Topography is one of the principal factors influencing soil formations, since it controls the depth as well as the nature of the profile (*12*, p. 48). This factor, together with a wide variation in textures, causes differences in soil profile development in Montgomery County moraines. Till and kame moraines have been differentiated on the map.

Generally speaking, the moraines of the county have a loess cover, in places 3 or 4 feet in depth and variously distributed. Underlying

FIGURE 21

In morainic areas the color pattern responds to relief. The hills are light in color, contrasted to the dark tones of the depressions. Note that at the extreme right in this photo a light tone is surrounded by dark tones. This has been caused by a very slight difference in relief.

the loess on the till moraine is a thin band of red-brown sand-clay which grades into a semi-granular light-brown till. The kame moraines consist of poorly assorted sands, gravels, and silts.

The two factors influencing highway construction and performance in these morainic areas are topography and soil textures. Deep cut and fill sections are commonplace wherever modern grade and alignment are required. Drainage, some frost action, and some pumping on heavily traveled roads can be found in relation to deep cuts in the till moraine. The chief difference in soil textures occurs between the areas designated as kame (granular) moraine and till (mainly silts and clays, with some gravel) moraine. The silt mantle which covers the morainic land form makes construction hazardous during rainy weather.

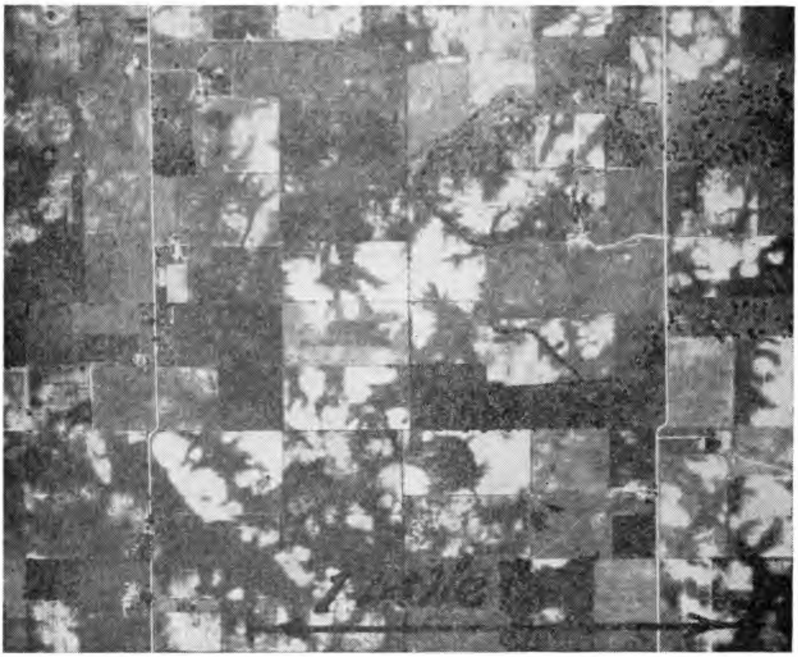


FIGURE 22

Till plains. In Montgomery County, gently undulating, relatively fine-textured soil areas whose airphoto pattern has not been complicated by bedrock or old drift contain this type of pattern. The soil color, which may be termed "mottled," has not been materially affected by land-use patterns of adjacent fields. Soil profiles in the higher, better-drained areas are shallow and contain less organic matter than soils in the depressions. A relationship exists among soil color, topographic position, and soil profile.

FIGURE 23

Re-sorted till pattern. On and bordering the re-sorted till area (lower left) are long, relatively low ridges. The texture of these ridges is fine, gravelly sand. Note that this ridge is discontinuous, yet assumes a more or less directional trend. Several pits (arrows) have been located along this ridge.

Till Plains. The till plain, or ground moraine as it is sometimes called, is the drift which became lodged at the base of the ice sheet or in the ice, and was left behind when rapid melting took place. The material is heterogeneous in composition and the topography is level to gently undulating.

The land form of the till plains is level to undulating. In general these plains are very broad, except where they are crossed by moraines, outwash plains, or other land forms.

The soil colors of the till plains show a light-to-dark-gray and white mottled pattern. Ordinarily these gray and white color tones are well integrated (see Figure 22), although there are places where one color tone is preponderant.

The drainage pattern is dendritic. The amount of surface drainage varies with the relief and texture. For example: the level land south of Shannandale shows an absence of drainage features; whereas the area between New Ross and the south county line shows a well-developed surface drainage pattern.

The weathered profiles are shallow, varying from three to four feet. The "B" horizon is frequently composed of sand-clays, below which the yellow-brown parent material is thickly set with small stones. The parent material consists of a heterogeneous mixture of sand, gravel, silt, clay, and boulders.

Soils of the till plain as a rule offer poor subgrade support, particularly in the depressed areas. For this reason high-level profiles have been advocated. Poor drainage conditions are also associated with soils of the till plains.

Re-sorted Till. This deposit assumes a broad low-lying depression, over which rivers flowed after emerging from the ice front. The wasting effect of the water flowing over these deposits has caused a rough sorting of the material so that patches of clay, sorted gravels or sands, and pond or lake silts and clays can be found. This type of deposit is called modified drift or re-sorted till.

The airphotos show that the land form is level to gently undulating, characterized by relatively low sinuous ridges which often parallel the minor drainage channels. These ridges are composed of a gravelly sand and are covered by a silty till shell. The ridges, having a northeast-southwest direction, can be detected on the photos from their land form and color. (See Figure 23.)

The soil color is predominantly dark gray with occasional light tones which are associated with the sandy ridges. The over-all uniform color tone is perhaps the most significant element on the airphoto.

Since this land form is composed of modified and roughly sorted sand, silt, and clays, there is little surface drainage. Where the groundwater table is close to the surface, deep ditches have been installed to lower the water table and thus render the land arable. These are situated in old channels in the lowest areas.

Soils along the ridges are porous and therefore show little profile development. In the flat to depressed regions the soil is plastic near the surface, but grades into a well-drained substratum. The drift is commonly stratified with thin sand layers which act as aquifers.

The several granular ridges associated with this deposit provide an excellent source of gravel for surfacing county roads. Pavement performance is variable because of textural differences encountered, often within very short distances.

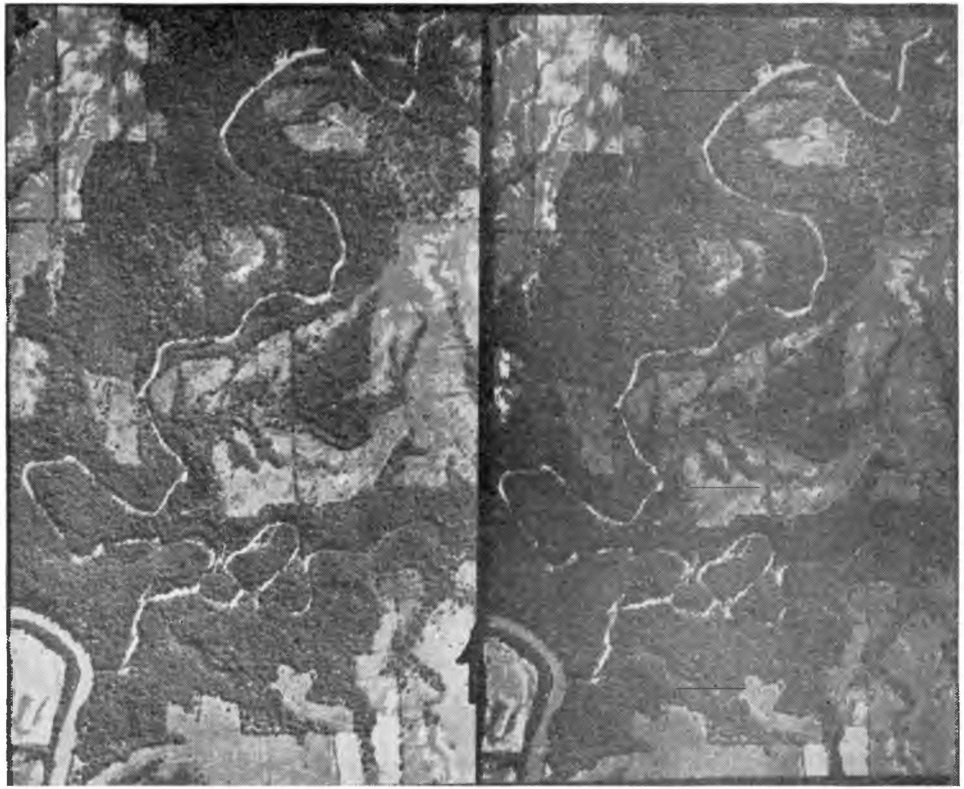


FIGURE 24

Wisconsin drift on rock. Sharp-crested divides, angular stream courses, and heavy forest vegetation are associated with this land form.

FIGURE 25

A ground view of a shale quarry in Montgomery County.

Drift-on-Rock. Intense erosion during Pleistocene times has carved narrow gorges, exposing many feet of sedimentary rocks. Between these gorges drift occurs as a mantle only, yet is usually of sufficient depth to prevent rock excavation along the divides.

Narrow, sharply winding streams with steep bluffs (Figure 24) are characteristic of this area. The divides are relatively flat in comparison, and show considerable erosion on the steepest slopes.

The color pattern of this highly dissected area is obliterated by dense vegetation along Sugar Creek, and along the principal tributaries. Between the streams along the divides the color is uniformly gray, except where it has been modified by white-fringed gullies.

The surface drainage has developed on this area as a consequence of the shallow soil profile and the many steep slopes. Except for the shallow drainage ways on the divides, the drainage is influenced by the underlying rock. The sharp angularity of this drainage system portrays the resistant nature of the bedrock.

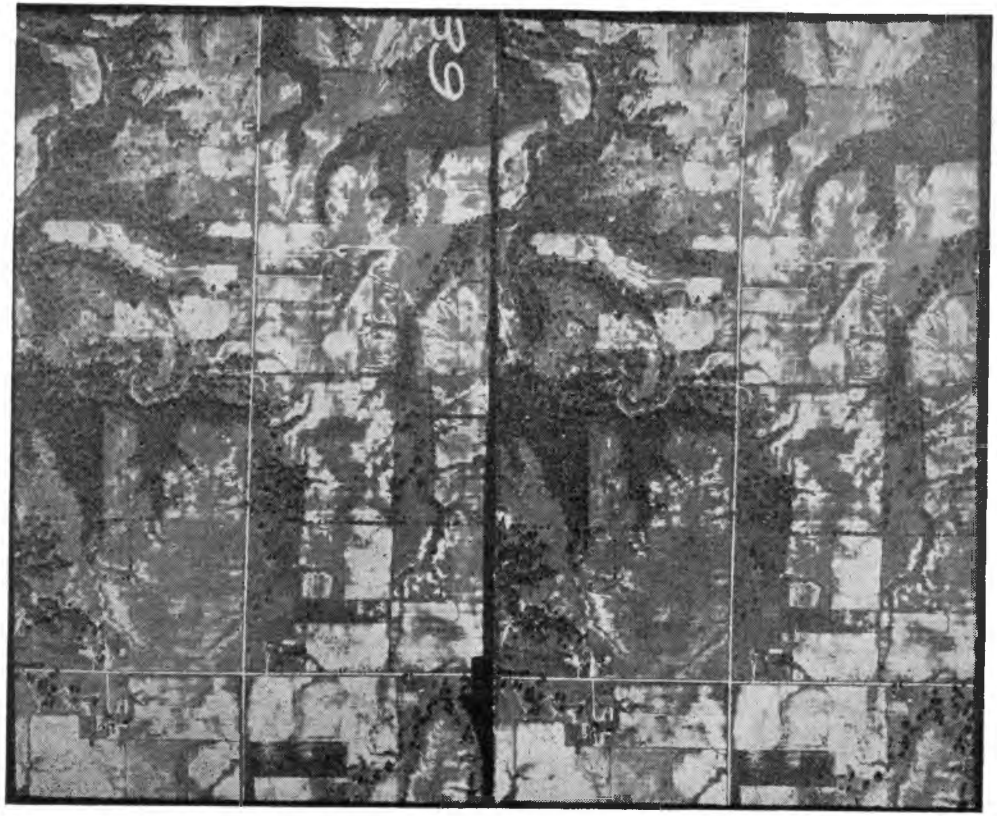


FIGURE 26

Loess-mantled Wisconsin drift on bedrock. The white fringes clearly illustrated in this stereopair reveal loessial characteristics. The fringes have formed as a result of the slumping of silt on the steep slopes.

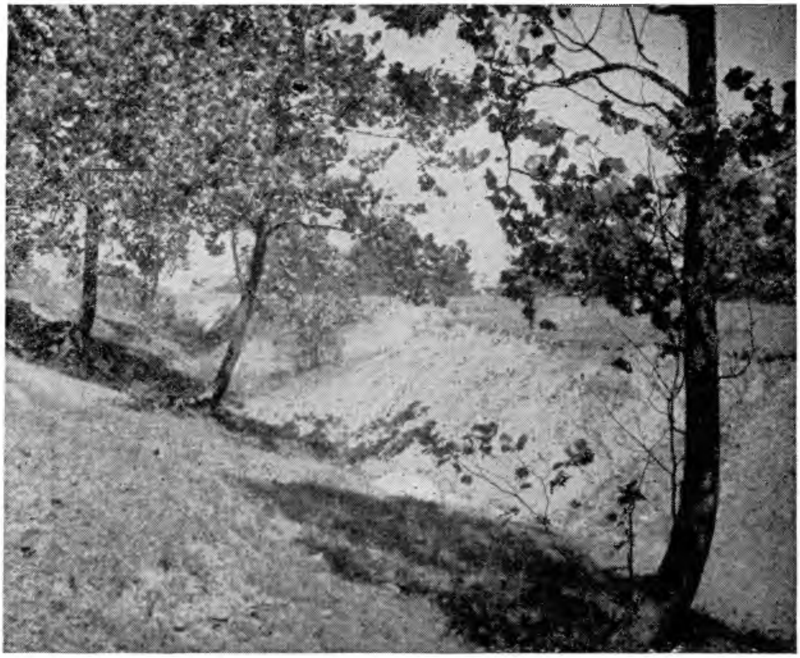


FIGURE 27

A gully formed in the silty topsoil of Figure 26.

The extensive gullying (erosion) which is found along Sugar Creek, within this rocky area, is caused by two factors, namely, topography and silt cover. The area is mantled by a few feet of loess, which, on the steep slopes, exhibits highly erosive properties. White fringes result from this type of gullying and "catsteps" form by the slumping of the silts. (See Figure 27.)

Shallow rock outcrops, coupled with heavy native forest and a highly erosive topsoil, make this area poor productively. Although some areas are being farmed, most of the area is devoted to pasture land.

The specific problems associated with these soils are those of erosion and bedrock excavation. In this area, delineated as drift-on-rock, the rock excavation occurs in cut sections between the upland and terrace, or at stream crossings. Because of the bedrock, the areal extent of this region is significant when bridge abutment or similar construction is anticipated.

MISCELLANEOUS SOILS

Muck and Peat. Muck and peat are formed in low areas of abundant vegetation where poor drainage conditions have existed over a

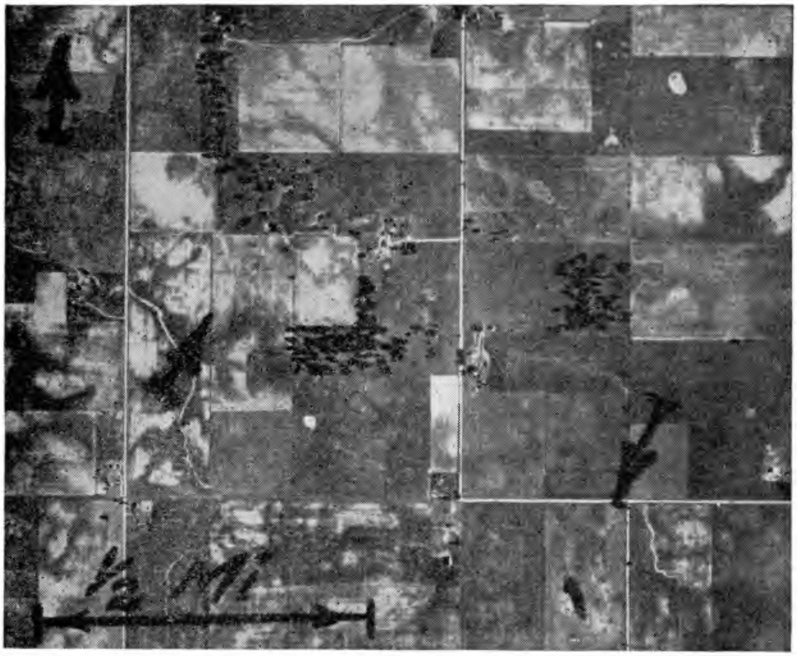


Figure 28

The arrows in this picture point to fields which lie in a boulder belt. The individual boulders are discernible, since shrubbery has been permitted to grow up around them.

considerable period. Muck is composed of thoroughly decomposed organic material (dead vegetative matter), considerable amounts of mineral soil material, and finely divided fibrous remains. Peat is similar, but is only partially decomposed, exhibiting many recognizable plant remains. Both muck and peat are treacherous soils and, since they are highly compressible, will not support any constantly applied load in the form of a fill or a structure without an appreciable reduction in volume.

Since many features indicative of muck areas have been previously discussed, there is no need for detail regarding their individual elements. It suffices to say that the principal identifying elements are as follows: depressed topographic position, dark color, and dense, swampy vegetation—all signifying poor drainage conditions. Both Lye and Black Creek swamps have been brought under cultivation by drains and open ditches. An excellent airphoto pattern of a muck area is shown in Figure 17.

Boulder Belt. The presence of a narrow belt of boulders has been detected on the aerial photographs. (See Figure 28.) This boulder belt

FIGURE 29

This photograph was taken at a highway underpass west of Crawfordsville. The wing wall shown here has been constructed upon pre-Wisconsin drift. The horizontal line (right center) marks the upper surface of this indurated drift. A highway, constructed in the same material, passes through this underpass.

enters the county northeast of the town of Linden, where it swings southwest to a point west of Darlington. The belt then turns south for a distance of about five miles, turns east, and passes out of the county immediately north of New Ross.

Old Drift. There is ample evidence to show that Montgomery County soils and topography were not affected solely by the Wisconsin

FIGURE 30

A broad, flat-bottomed gully, which may be sketched from the airphotos, is shown here. Apparently gully erosion was retarded when the dense subjacent drift was reached.

ice sheet. Several locations were found throughout the county where the Wisconsin till occurred only as a surface mantle, in places less than four feet. This underlying drift is radically different in texture, structure, and density, and has the appearance of very old drift, which, in fact, it is. Virtually all the large terraces of Montgomery County are underlain by this drift; and although the terraces are frequently deep, they do not extend to the level of the present stream channels as might be expected. In some localities where the gravel terrace is roughly a hundred feet above present Sugar Creek, the gravel is only five or ten feet in thickness.

This old drift, because of its high natural density, has altered the topography and drainage characteristics of the overlying materials so as to give a complex airphoto pattern. This fact is exhibited by the terrace patterns northeast of Crawfordsville, and by the Wisconsin till plain pattern west of Ladoga. More research is needed throughout

Indiana, however, to establish patterns where this old drift is a factor in forming the soil pattern.

Typically, where the unoxidized blue-gray phase of this drift is exposed, it is composed of a very dense till, cut by numerous joint planes intersecting at such angles as to give the clay a very characteristic fracture, resulting in angular fragments one-half to an inch and one-half across. The groundmass of this till is finely ground rock-flour, but is gritty from the presence of small sand grains.

One-half mile west of Ladoga along the bluffs of Big Raccoon Creek is an excellent exposure of this old drift. At this particular location the overlying Wisconsin drift is less than ten feet deep, differing materially in natural density and composition from the old drift. Stream erosion here has been altered upon reaching this dense till and, as a result, gully shapes assume broad, flat bottoms with relatively steep sides. The till found at this location, and at others along Cornstalk Creek, is similar to those examined along Walnut Creek, and Little Sugar and Sugar

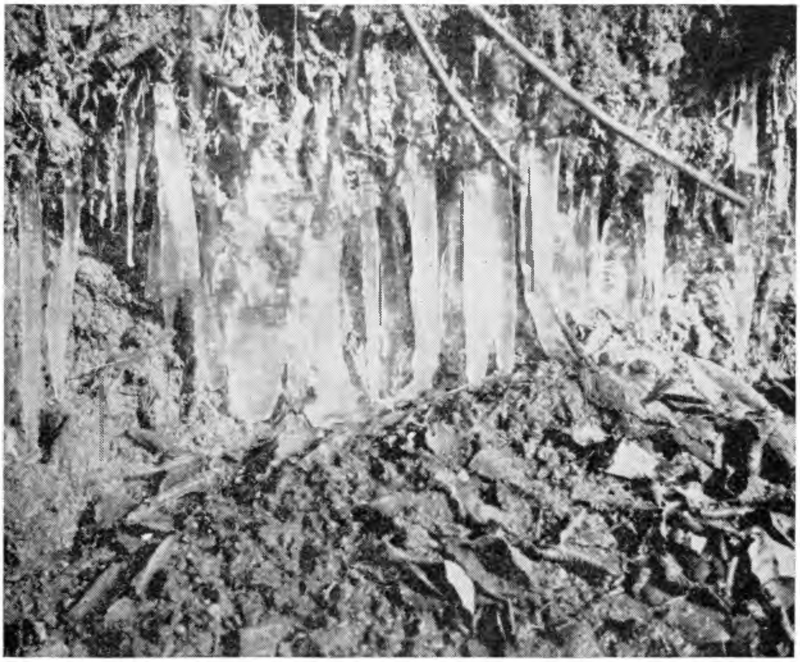


FIGURE 31

Formation of icicles. A situation caused by water's seeping and freezing along the line of contact of the gravel terrace and impermeable pre-Wisconsin drift.

creeks. Exposures visited by Dr. W. D. Thornbury (*11*, pp. 35 and 116—117) were also examined by the writer. The Illinoian drift as viewed in these exposures, although few in number, bears a striking resemblance in composition and structure to most of the till designated as "old drift" in this paper.

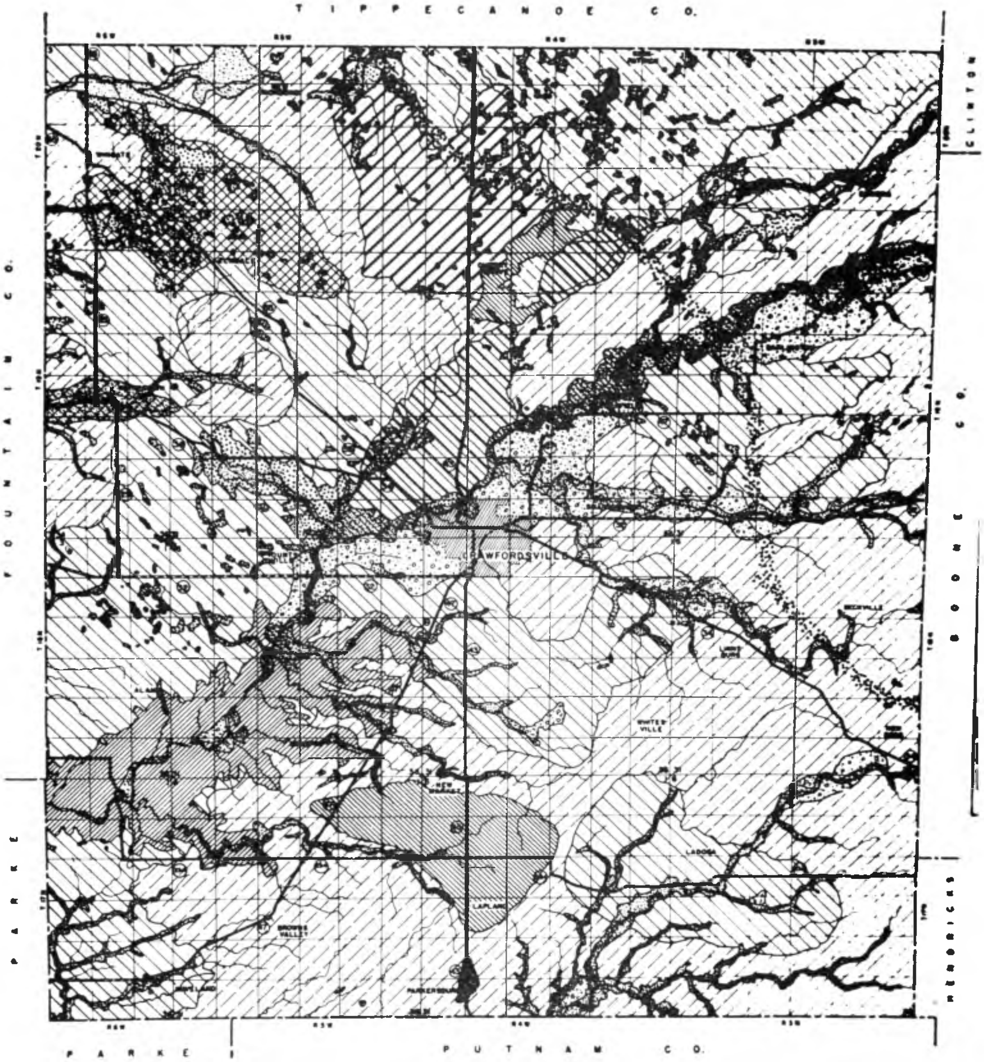
No exposures were located in Montgomery County in which both Illinoian and pre-Illinoian tills could be distinguished, although the writer has inspected exposures in contiguous counties where pre-Illinoian has been recognized. For this reason, pre-Illinoian drift may be exposed along the deepest gullies in Montgomery County; however, further studies are needed to definitely determine the age of these materials.

Because of the dense, indurated nature of this old drift, under most circumstances it is extremely difficult to excavate. Moreover, it is impervious and therefore maintains a high ground-water table. This is well illustrated by Figure 31, a condition which is common along the bluffs of Sugar Creek. Also, obviously of significance in gravel exploration is the fact that thin gravel deposits overlying the old drift may be mistaken for thick gravel terraces.

BIBLIOGRAPHY

Geology, Geomorphology and Physiography

1. Carman, J. E., "Further Studies of the Pleistocene Geology of Northwestern Iowa," *Iowa Geol. Survey,* Vol. XXXV, pp. 103-116, 1929.
2. Collett, John, "Montgomery County," 7th Annual Report, *Geol. Survey of Indiana,* pp. 361-422, 1875.
3. Indiana, Department of Geology and Natural Resources, *28th Annual Report,* pp. 42-77, 1903.
4. Indiana, Department of Geology and Natural Resources, "Clays of Montgomery County," *29th Annual Report,* pp. 341-347, 1904.
5. Indiana, Department of Geology and Natural Resources, "Road Materials of Montgomery County," *30th Annual Report,* pp. 615-624, 1905.
6. Kay, G. F., "Some Features of the Kansan Drift in Southern Iowa," *Bulletin Geol. Soc. America,* Vol. XXVII, pp. 115-117, 1916.
7. Fidlar, M. M., "The Preglacial Teays Valley in Indiana," *Jour. Geol.,* Vol. LI, pp. 411-418, 1943.
8. Leverett, Frank, "The Illinois Glacial Lobe," *U. S. G. S. Monograph 38,* Government Printing Office, Washington, D. C., 1899.
9. Leverett, Frank, and Taylor, Frank B., "The Pleistocene of Indiana and Michigan and the History of the Great Lakes," *U. S. G. S., Monograph,* Vol. 53, 1915.



ENGINEERING SOILS MAP

OF

MONTGOMERY COUNTY

INDIANA

FIGURE 32

Soil map of Montgomery County, Indiana.

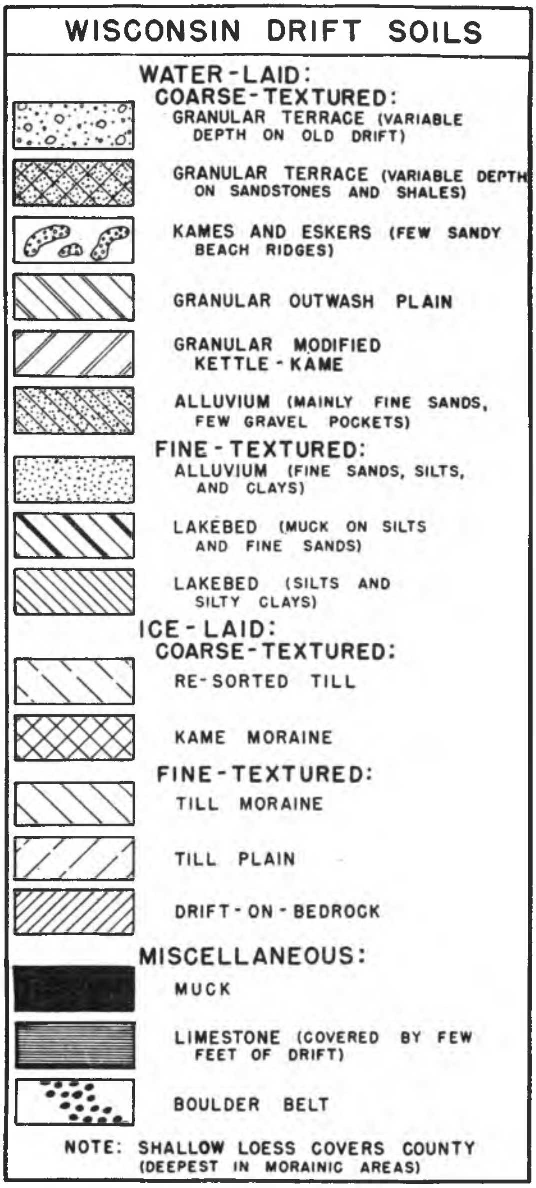


FIGURE 32

Soil map of Montgomery County, Indiana

10. MacClintock, P., "Recent Discoveries of Pre-Illinoian Drift in Southern Illinois," *Report of Investigations No. 19, State Geol. Survey,* 1929.

11. Thornbury, W. D., "Glacial Geology of Southern and South-Central Indiana," *Proceedings of the 47th Annual Meeting Indiana Academy of Science,* Vol. 41, Wm. B. Burford Printing Co., Indianapolis, 1937.

Pedology and Soil Testing

12. Belcher, D. J., Gregg, L. E., and Woods, K. B., "The Formation, Distribution, and Engineering Characteristics of Soils," *Engineering Bulletin of Purdue University, Research Series, No. 87,* 1943.

13. Jenkins, D. B., Belcher, D. J., Gregg, L. E., and Woods, K. B., "The Origin, Distribution and Airphoto Identification of United States Soils," *C.A.A. Technical Development Report No. 52,* 1946.

14. Bushnell, T. M., "The Story of Indiana Soils," Purdue University, *Agricultural Experiment Station, Special Circular I,* 1944.

15. Grove, Jones B., "Soils Survey Report of Montgomery County, Indiana," U. S. D. A., Bur. of Soils, pp. 1473-1494, 1912.

Aerial Photography

16. Belcher, D. J., "Identifying Landforms and Soils by Aerial Photographs," *Proceedings of the 30th Annual Road School,* Purdue University, 1944.

17. Belcher, D. J., "The Development of Engineering Soils Maps," *Proceedings of the 29th Annual Road School,* Purdue University, 1943.

18. Belcher, D. J., "Airphotos Illustrating the Origin, Distribution, and Airphoto Identification of United States Soils," Appendix B of C.A.A. *Preliminary Technical Development Report No. 52,* 1946.

19. Hittle, J. E., "The Use of Aerial Photographs in Identifying Granular Deposits and Other Soils," *Proceedings of the 29th Annual Road School,* Purdue University, 1943.

20. Frost, R. E., "Location of Granular Materials from Aerial Photographs," *Proceedings of the 32nd Road School,* Purdue University, 1946.

21. Frost, R. E., "The Use of Aerial Maps in Soil Studies and Location of Borrow Pits," *Proceedings, Kansas Highway Conference* 1946.

22. Frost, R. E., and Mollard, J. D., "New Glacial Features Identified by Airphotos in Soil Mapping Program," *Proceedings, Highway Research Board,* December, 1946.